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ABSTRACT

The goal of my multi-study research program has been to learn how to engage all students in learning science. Most learning theories applied to science pedagogy take either a psychological or a sociocultural perspective and hence ignore either sociocultural or motivational factors when considering classroom learning. Based on my own research studies, as well as on a complex of theories from a range of disciplines, I propose including psychological, psychosocial and sociocultural perspectives in a more holistic perspective-a biosocial system perspective. Because it allows for the interdependence of the various levels of the ecological system in which learning takes place, I believe it has considerable potential to advance knowledge about teaching and learning. This biosocial system perspective focuses in particular on how the mind is affected both by the way the embodied human brain functions and by its sociocultural context. As applied to science pedagogy, it highlights neglected subconscious processes involved in interpersonal communication at both levels of activity. On the one hand, it accords a significant role in learning to intuitive processes and feelings, and interpersonal relationships, and on the other hand, addresses the potentially problematic nature of classroom discourse in science. Such a perspective grew as I carried out several research studies in science education in Brisbane, Australia, including a study that explored ways of helping disadvantaged Year 8 students engage in learning science. (Contains 68 references.) (Author)

Improving Engagement in Science: A Biosocial System Perspective

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Abstract

The goal of my multi-study research program has been to learn how to engage all students in learning science. Most learning theories applied to science pedagogy take either a psychological or a sociocultural perspective and hence ignore either sociocultural or motivational factors when considering classroom learning. Based on my own research studies, as well as on a complex of theories from a range of disciplines, I propose including psychological, psychosocial and sociocultural perspectives in a more holistic perspective—a biosocial system perspective. Because it allows for the interdependence of the various levels of the ecological system in which learning takes place, I believe it has considerable potential to advance knowledge about teaching and learning. This biosocial system perspective focuses in particular on how the mind is affected both by the way the embodied human brain functions and by its sociocultural context. As applied to science pedagogy, it highlights neglected subconscious processes involved in interpersonal communication at both levels of activity. On the one hand, it accords a significant role in learning to intuitive processes and feelings, and interpersonal relationships, and, on the other, addresses the potentially problematic nature of classroom discourse in science. Such a perspective grew as I carried out several research studies in science education in Brisbane, Australia, including a study that explored ways of helping disadvantaged Year 8 students engage in learning science.

Improving Engagement in Science: A Biosocial System Perspective

In schools and society more generally there is considerable dissatisfaction with the level of engagement with science during the compulsory years, with retention rates in science in later years, and with unsatisfactory scientific literacy in the general population (AAAS, 2000; Fensham, 1992; Osborne & Collins, 2000). In Australia, this has recently been described in relation to a conspicuous gap between the ideal and the actual state of affairs in science classrooms (Goodrum, Hackling & Rennie, 2001). The problem of low engagement with science motivated the series of research studies addressed in this paper that resulted in a new conceptualization of the learning process.

The A Side of the Coin: Affirming Student Affect to Arrest Alienation

Science education research in Australia in recent decades has generally been under-girded by a range of constructivist epistemologies (individual, social and radical versions of constructivism) that parallel a continuum of learning theories extending from a focus on individual cognition (cf. Piaget, 1969/1991), to a focus on cognitive development through social processes (cf. Vygotsky, 1966/1991), with the intermediary position perhaps being the radical constructivist position[i] of von Glasersfeld (1993). Regardless of the extent to which they see cognition as the result of individualist or social practice, constructivists have tended to see themselves as social constructivists, particularly if they advocated group discussion as an exemplary teaching practice, with Rosalind Driver and colleagues (beginning with a seminal paper by Driver & Easley in 1978; s.a. Driver, 1989) having been a major influence.

However, theories of learning associated with constructivism tend to restrict the focus to psychological factors, and, within these, to cognitive factors, as though learning is almost entirely a matter of logical processing, albeit one which is facilitated by group discussion among peers. The other factors present in the social context that support learning are left largely unexplained, and emotional factors are rarely discussed. In fact in general both the motivation to learn to think like a scientist and familiarity with this mode of thinking seem to be assumed, both of which assumptions seem unwarranted, especially in students who have little desire to specialize in science. By contrast, in this paper I want to propose that if teachers are made aware of the subconscious processes necessary for engagement in science at both the personal and social levels, they may be better able to prevent alienation from science at the junior secondary or middle years level of schooling.

Prior experience with a critical approach to literacy teaching, especially as it has applied in adult literacy teaching, was an important factor in bringing about change in my thinking about teaching and learning. The original critical literacy theorist, Paolo Freire saw the learning of literacy as "no longer an inconsequential matter of ... memorizing an alienated word, but a difficult apprenticeship in naming the world" (Freire, 1970, p. 511). Similarly Treloar (1994) argued that literacy learning involved much more than learning to read and write words in particular contexts according to particular rules; more fundamentally it involved learning new ways of relating to other people and to one's world, including changes in the power dynamics in relationships and even in one's self-concept. However, while acknowledging the sociocultural variables involved she also pointed out the psychological factors involved. She emphasized the psychological difficulties involved in changing one's identity—a possible or even likely outcome of becoming more literate—and commented that such difficulties may only be overcome with a struggle. She argued, "[W]hat is missing from the argument of the critical theorists is any attention to the process by which individuals undergo change. There is no sense that this may prove difficult or may be resisted" (p. 15). She believed that it *was* likely to be resisted until students changed their conceptualization of themselves as individuals who, for example, typically did not use a range of literacy practices or who were in particular power structure arrangements with other people.

Even though Treloar seems to be coming from an individualist her point of view would be consistent with a systems perspective in which people are seen as developing social practices (including language) in response to their environment, and only changing them when the environment and meaning system permits this. However, it is significant that she saw these as necessarily involving conscious struggle, and hence agency (and will) at the personal level.

The B Side of the Coin: Throwing the Baby out with the Barthes water

On the other hand, there has been a tendency in some sociolinguistic thinking (e.g., Lemke, 1995) derived to some extent from Barthes (1977) and his phrase "Death of the Author" (pp. 142-148) to play down the importance of individualistic psychology on the grounds that it exaggerates the importance of the individual and neglects the extent to which language practice is socially determined. (This is paralleled in the broader literature of postmodernism in the phrase "death of the subject", cf. Giroux, 1992). I agree that the tools of thinking and language use are socially determined, but would caution against throwing the baby out with the bath water. I believe that it is useful for educators to see learning as both a social practice, and as a minds-on activity, and to take into account the "psychology" of humans as living organisms. Giroux (1992) wrote

> [T]he speaking subject must be decentered but [that] does not mean that all notions of human agency and social change must be dismissed. Understood in these terms, the postmodernist notion of the subject must be accepted and modified in order to extend rather than erase the possibility for enabling human agency. At the very least, this would mean coming to understand the strengths and limits of practical reason, the importance of affective investments, the discourse of ethics as a resource for social vision, and the availability of multiple discourses and cultural resources that provide the very grounds and necessity for agency. (pp. 27-28)

An extreme "death of the subject" view also treats individuals as differing fundamentally, as having no essential continuity, between different situations in which they perform in automatic response to those situations. This seems to me to ignore the historical impact of the physical and social world on the brain/body of a person. I take a view of knowledge as being embodied such that there are individual differences in how communication is experienced and created, and that this consciousness is continuous to some extent across time and contexts. In this paper, I will argue that a sociocultural approach that does not take into account the personal experience of students is one that is likely to come to grief in the classroom, just as much as a psychological one that does not take into account the extent to which the use of language (including thinking and learning) is dependent on social practice.

A considerable body of literature that I will summarize briefly in the following section, when taken as a whole, suggests that engagement in learning is a process involving both personal and social factors, with physiological processes such as emotions and intuitions being essential to both cognitive and social practices. If this is the case, and if we want to improve science pedagogy so that it can address the needs of all future citizens and not just those who are personally disposed to learn science[ii] then such factors need to receive attention in theories of teaching and learning for science designed for all students. The main foci for this discussion will be the implications of my research for a theory of learning and teaching, particularly in the domain of science, but perhaps also for learning more generally. The series of studies that this paper analyses had the following objectives in relation to science education:

- to study the relationship between motivational variables and intellectual engagement in science classrooms,
- to explore the relationship between language use and engagement in learning in science classrooms, and
- to construct a model of learning that relates motivation, communication and engagement.

Theoretical Underpinnings

The biosocial system theory of learning and development[iii] that I want to argue for in this paper can be seen as the integration of theories from a range of perspectives, including psychological, psychosocial, and neuroscience theories of learning and change, and sociocultural theories including psycholinguistic and sociological theories.

Personal Factors in Learning

There are many **psychological theories** in education that stress the importance of personal factors in learning. I have listed these in detail in a recent paper on affective factors in intellectual engagement (Hanrahan, 2002b) and will only give a few examples here. Concepts such as autonomy, motivation, locus of control, self-efficacy, thoughtfulness, metacognition and attribution have all been implicated in theories about self-regulation of learning from a cognitive science, critical literacy or humanistic perspective (e.g., Bandura, 1989; Blumenfeld, Mergendoller, & Puro, 1992; Borkowski, Carr, Rellinger, & Pressley, 1990; Boud, 1987; Freire, 1970; Grolnick & Ryan, 1987; Hanrahan, 1999b; Paris & Winograd, 1990; Rogers, 1969, Weiner, 1990). Further, neuroscientists such as Damasio (1994) and cognitive scientists focusing on creativity (see Hanrahan, 2003, for a brief summary) have all stressed the important role of the emotions in everyday thinking processes and scientific intuition. Theories from clinical and counseling psychology (e.g., Beck, 1975; Rogers, 1969) have also been useful in addressing factors affecting motivation and change, including self-worth and affirmation theories, and cognitive behavioral theories.

However on their own, these theories do not fully explain motivational problems in science classrooms as documented in the literature (e.g. by Lemke, 1990; Fensham, 2002). As long as the discourse used is impenetrable to students, both students and teachers will experience a sense of frustration (Hanrahan, 1999a; 2002c). Sociocultural theories are more useful for addressing problems in this area. Even though I believe that they deal with social practice at a generalized level where feelings are seen as social artifacts or performances rather than as important intermediaries in social processes, sociocultural theories are better at explaining the dynamics of the tacit processes that lie behind the ways in which teachers and students make sense to each other—or fail to do so (cf. Lemke, 2001). I will now turn to a brief discussion of sociocultural theories, which I have discussed at more length in Hanrahan (2002c).

Social Factors in Learning

Sociocultural theories that aim to inform pedagogy argue for the integral importance of the broader social context in learning. In a comprehensive review of sociocultural research in science education, Lemke (2001) reported that research in this area has largely focused on social interactions in classrooms, on cultural conflict between normative science and indigenous cultures, on minorities, and on gender equity. In contrast to the psychological perspectives sketched above, the focus has moved from processes operating within the individual to processes operating within social groups and society more generally, and "what matters to learning and doing science is primarily the socially learned cultural traditions of what kinds of discourses and representations are useful and how to use them, far more than whatever brain mechanisms may be active while we are doing so" (Lemke, 2001, p. 298).

One group of sociocultural theories that has been particularly illuminating can best be described as **sociolinguistic theories**. These demonstrate that language is always used within discourse systems and performs many functions simultaneously, including ideational (conveying the subject matter content), textual (performing a role in a particular kind of text or genre), and interpersonal and orientational functions (negotiating power relationships and identity). They include theories about discourse and/or genre (Gee, 1993; Halliday, 1994; Halliday & Martin, 1993; Kress, 1985; Lemke, 1990, 2001), critical literacy (Freire, 1970; Luke, 1997; McLaren & Lankshear, 1993), and critical discourse analysis (Fairclough, 1989; Luke, 2002). Some of these have been influenced by Foucauldian notions of the social evolution of knowledge and the way power relations are embodied in social practice as 'discursive formations' (cf. Foucault, 1969/1972).

Another area of sociocultural theory that has implications for education, including science education is sociology and in particular the sociology of education. **Sociological theories** have serious implications for equity issues in science education, and, in the examples provided here, particularly in relation to factors related to social class (Bernstein, 1990; Bourdieu, 1974). Bourdieu wrote about various types of 'capital' that children might inherit. Familiarity with middle class ways of using language is part of the linguistic and cultural capital that is available to some students but not others. Teachers may not be aware of the extent to which education systems—and science education is possibly the most conservative in this regard—are based on assumptions of a particular level of cultural capital, and hence may not be aware of the extent to which those who do not possess such capital are doubly disadvantaged. Bourdieu (1974) wrote:

> [T]eachers assume that they already share a common language and set of values with their pupils, but this is only so when the system is dealing with its own [aristocratic] heirs. By acting as if the language of teaching, full of allusions and shared understanding, was 'natural' for 'intelligent' and 'gifted' pupils, teachers need not trouble to make any technical checks on their handling of language and the students' understanding of it, and can also see as strictly fair academic judgements which in fact perpetuate cultural privilege. ... [A]s the gap between university language and that spoken in fact by the different social classes varies greatly, it is impossible to

> have pupils with equal rights and duties towards university language and use of language without being obliged to hold the gift responsible for a number of inequalities which are primarily social. (pp. 39-40)

Bernstein (1990) explained such a situation in terms of elaborated and restricted language codes, visible and invisible pedagogies, classroom pacing and sequencing rules, classification and framing, and recognition and realization rules. He used these terms to identify factors that he believed governed the kind of education students would be likely to experience, depending on their class origins (with derivative effects on many other groups who were culturally different from the dominant middle class group). He demonstrated how school structures and discourse expectations interact with the preferences and resources students bring to school to the advantage of those whose preferences and resources most match those of school requirements and to the detriment of other students. The result could be a severely restricted (and boring) curriculum for a group at one end of the scale with little practice in higher order thinking processes and little access to explanatory principles and relevant applications. At the other end of the scale, the result could be a challenging and rewarding curriculum, with most of students' time being spent on understanding concepts and applying them to situations relevant to the students' lives. Such theories discount the notion that school success is largely a matter of genetic endowment and personal effort, and stress the importance of social and cultural factors in deciding who is most likely to find that personal effort on their part will be rewarded.

In contrast to psychological theories the sociocultural theories discussed in this section demonstrate how much social practice, including language use, is governed or restricted by cultural norms and how little thinking is actually under personal control. Such knowledge can be useful to understand what prevents "conceptual change" in science classroom, but can only be transformative for learning if the extent to which individuals are actors as well as reactive agents is also recognized. This brings me to a third group of theories of learning, which could be called *psychosocial* theories. They recognize both psychological and cultural factors but have not explicitly integrated these into an en-encompassing theory.

Psychosocial theories of learning

Psychosocial theories of learning range from those that see learning as essentially an individual cognitive process but influenced by social factors to those that see learning as essentially a sociocultural process, but allowing for individual factors. Within this range, I would include social constructivism (Driver, 1989; Solomon, 1989), conceptual change theories (e.g., Posner, Strike, Hewson, & Gertzog, 1982; Pintrich, Marx & Boyle, 1993; Roth, 1990), classroom climate or learning environment theories focusing on the interpersonal teacher-student relationship (Fisher, 1992; Wubbels, 1993), and possibly situated cognition theories (Collins, Brown & Newman, 1989; Roth & McGinn, 1997), though some of these may find a better fit in the following section.

An example of a theory that covers the range is Kathleen Roth's (1992) account of conceptual change teaching. This is a significantly different account from that which she gave in Roth (1990). In the mean-time she had become aware of how much more was being communicated by science teachers than knowledge about scientific concepts; she had come to realize how the tacit messages being conveyed along with the intended curriculum may, in fact, have been undermining additional goals on the part of the teacher of having students develop positive attitudes towards science, understand the nature of science, and learn for understanding. To help students learn with understanding, she stressed the importance of moving from a "workplace environment" metaphor (where getting tasks completed was the main goal) to "a learning community of scientific inquiry" where understanding within a community context was the goal (p. 11). Her conceptual change model had become more sociocultural. She wrote:

> As I now think about the conceptual change model of instruction, what I used to think of as the model--eliciting and challenging students' ideas, contrasting students ideas with scientific explanations, providing multiple opportunities for students to use concepts to explain real-world situations--is now just a piece of the model, a piece that has no meaning ... unless it is carefully connected with children and their ideas in a learning community that encourages and enables active inquiry and sense making. One way of representing my new vision of the model is to envelop the model in a learning environment needed to support learning versus just getting work done." (p. 11)

'Situated cognition' theories (derived from Lave, 1988) could also be included in this category, although in a strong version (cf. Roth & McGinn, 1997) they may be more purely sociocultural. While social factors are seen as integral to the development of the complex of beliefs and practices (including self-monitoring processes) that result in successful engagement in school learning, they are seen in relation to cognitive factors. Also included is a notion of motivation for metacognitive practices being dependent on the learner identifying with the community promoting the practice to be learnt. The version of a 'cognitive apprenticeship' as proposed by Collins, Brown and Newman (1989), advises that cognitive, motivational and social factors all be attended to simultaneously. They insist equally on the psychology and sociology of learning.

An approach that includes the notion of situated cognition and that recruits knowledge from a range of disciplines is the literacy teaching approach promoted by the New London Group (1996)[1]. This is an approach to the teaching of literacy (or rather 'multiliteracies') that combines features recommended by researchers from a range of perspectives–cognitive science, social cognition, and sociocultural approaches to language and literacy. These authors emphasize four factors in their complex of "a pedagogy of multiliteracies": Situated Cognition, Overt Instruction, Critical Framing, and Transformed Practice. They link two discourses: the cognitive science approach that commonly describes learning almost exclusively in terms of individual consciousness and agency, and sociocultural approaches that, by contrast, emphasize the extent to which learning is determined by prevailing social practice, since "notwithstanding these different relationships of structure and agency, all meaning-making always involves both" (The New London Group, p. 81). As they define it, *Situated Cognition* refers to learning in a community environment such that new learning is linked to students' lifeworlds, which the New London Group define as "spaces for community life where local and specific meanings can be made" (The New London Group, 1996, p. 70). *Overt Instruction* refers to the practice of making explicit and focusing students' attention on the important features of what is being learnt, so as to allow students to structure it in a way that allows them to control the "intrasystemic relations of the domain being practiced" (The New London Group, p. 86). *Critical Framing* refers to activities that give students a perspective that makes them more aware of the cultural locatedness of what they are learning so that they are not limited to seeing it as the sole legitimate view of the world. Finally, *Transformed Practice*, like 'reflective practice' refers to changes in behavior brought about by actively using new learning for one's own purposes, that is, being a fully literate person in relation to a particular context. This takes one back to the beginning of the cycle, to Situated Learning. If it were not for the fact that she was writing much earlier, Colvin (1991) could be seen to be summing up the multiliteracies approach by defining critical pedagogy in the following way:

> [A] critical pedagogy ... must create learning contexts that will be engaged, personal, non-threatening, transparent and debate-oriented if transformative rather than transmission learning is to occur. ... The assumption is that greater information and a true dialectic mean greater power. (Colvin, 1991, p. 108-109)

Recent research in schools to identify the factors responsible for a high level of 'authentic' student achievement has resulted in practical theories that highlight both psychological and sociocultural factors important in successful teaching and learning in classrooms (e.g., Lingard, Mills & Hayes, 2000; Newmann & Associates, 1996). In Australia, a large, system-wide longitudinal study by Lingard, Mills & Hayes (2000) resulted in the listing of a complex of psychological and sociocultural factors that they have called "productive pedagogies", which address learning in a way that attends to social and ethical issues at the same time as seeking to enhance intellectual quality of student learning. Beginning with the findings from the Newmann and Associates (1996) research on successful school reform as measured by authentic achievement by students, Lingard, et al. broadened the scope of their research to explore pedagogies that also affected personal and social achievement and well-being. The four resulting categories of "productive pedagogies" were Intellectual Quality, Connectedness, Supportive Classroom Environment and Recognition of Difference. The first two had much in common with the Newmann & Associates (1996) definition of "authentic pedagogy" which required (of students) higher order thinking, deep knowledge, substantive conversations, and connections to the world beyond the classroom.

The theories addressed in this section all include a mix of cognitive, psychological, and sociocultural factors, with the combination of factors being theorized to greater or lesser extents. To the extent that are integrated into a single theory, they could be placed in the following section, where I address system theories of learning.

Learning as Practice within a Material System

Ecosystem theories assert that human behavior is learnt both within and as a response to a complex of interdependent social, organic, and inorganic systems. Explicit ecosystem theories include "ecosocial system" theory (Lemke (1995, 2001, 2002), and "the biological roots of human understanding" (Maturana & Varela, 1992). These emphasize the interdependence of learning on both the immediate and broader contexts, describing knowledge as *practice* within a multi-layered context rather than as something that can be abstracted and analyzed independently of context, or contained within " the mind" in the absence of practice.

As I shall now go on to explain somewhat briefly (more detail and other converging theories are provided in Hanrahan, 1998a), both of these theories conceptualize knowledge as practice, practice that has been learnt/constructed over time, as a result of interaction between the social and physical systems of which one's practice is a part. In effect, they are saying that one's knowledge depends on (and is limited by) the personal resources and tools that one has at one's disposal and that these are determined not only by one's social history but also by material structures within which social practice is developed, including one's living body.

`Ecosocial System' Theory (Lemke, 1995)

Lemke, a social semioticist whose eco-social system I have referred to above (see also Lemke, 1990, 1995, 2001, 2002), sees knowledge as emerging as part of particular situations of social practice, rather than as an object that can somehow be detached from the contexts in which it is occurring. In this social semiotic theory, language and other semiotic practices are seen as having many semiotic functions simultaneously, as well as being dependent on the material interaction system to a greater or lesser extent (although the latter is de-emphasized).

For Lemke (1995) the emphasis was on the part played by one's cultural system in determining semiotic (and hence thinking) practices such as language, with the part being played by the individual being downplayed to counteract the popular belief that an individual was largely responsible for and in control of her or his own thinking. Lemke distinguished between meaning systems and interaction systems and linked this with possibilities for change in meaning systems. A *meaning system* consisted of the knowledge, both tacit and conscious, that a particular social group had about its practice, including its cultural activities such as language and art. An *interaction system* was a different way of accounting for the same material system that supported the meaning system(s). It contained all the material interactions that were taking place in situations whether or not they were accounted for by the meaning system(s) at that particular time.

Meaning systems and interaction systems were thus interdependent with each placing limits on the possibilities for the development of the other. This is similar to Maturana and Varela's explanation of knowledge as what we "bring forth" together (Maturana & Varela, 1994, p. 234), but places less emphasis on the limits of the human physiological system, whose workings are not seen as being so important for a theory of social action.

`The Biological Roots of Human Understanding' (Maturana & Varela, 1992)

For Maturana and Varela (1992) the emphasis was on the co-determination of practice by an organism and its environment as they co-adapted, and the way this was allowed for or limited by that organism's history and structural dynamics (its ontogenic and phylogenic adaptations to its environment). As such the latter theory allowed a greater emphasis on the individual (organism) and the way its knowledge was limited by its biological structure (including its organs of perceptions and the rest of its neural and other communication systems) as well as its history. That is, an individual's behavior was seen as the result of the history of interactions between that particular organism and its environment but, as in Lemke's theory, an individual was not seen as acting independently of the social system to which she or he belonged, nor was behavior seen as having meaning outside the system to which it belonged.

In developing their theory of the biology of human understanding Maturana and Varela (1992) took into account findings in their own neurophysiological research and other biological research. They saw all living organisms as having achieved internal autonomy (*autopoiesis)* at the same time as necessary effective coupling with other systems in their usual environment. This meant that they could not agree with a representational view of knowledge as 'information' that is held and used for action. Knowledge is practice with "animal and environment as two sides of the one coin" (p. 253), or as mutually dependent systems, with neither being able to be defined effectively in isolation from the other. "Everything said is said by someone" (p. 26) as part of current social practice, such that "all knowing is doing" and "all doing is knowing" (p. 26).

It follows then that knowledge in humans is the result of shared historical and present circumstances and therefore is not restricted to conscious cognitive activity (Hanrahan, 1998a[iv]). It represents the sum total of the structural changes resulting from their history of recurrent interactions with other parts of their environment, whether they are conscious of it or not. Moreover, there is no way that they can know outside of their interactions with their environment, and what counts as relevant in this relationship is predetermined by the limits of their senses and history. In fact the world that they *know* is really a world that they "bring forth" (Maturana & Varela, 1992, p. 234). Understanding the part played by components in a system involves understanding that no environmental or even internal factor is ever a *cause* of change in the organism; the most it can be is a trigger for a chain of events whose outcome will depend on the structure and functioning of the system which itself will depend to some extent on the presence of other elements in the organism's environment. In this way, even genes cannot be seen as "stored information". This is to the advantage of the organism, as it means it develops in such a way that its essential features are compatible with its environment rather than in a way that, being predetermined, might make it poorly adapted to a changing environment. (Similarly, Lemke stresses the importance of what he calls an "epigenetic strategy" (1995, p. 160) for the survival of systems in a changing environment).

The notion of knowledge as practice enables recognition of knowledge that is not necessarily part of logical processes, including knowledge used outside conscious awareness. Once it is allowed that logical means are not the only means of acquiring new knowledge, then we can begin to look more openly at other processes involved in learning and change and see that they go far beyond analytic thinking.

Maturana and Varela's (1992) theory of the biological roots of human understanding begins with the lowest form of life, included biochemical and physiological processes, and shows the gradual progression of mutually adaptive behavior in all systems and subsystems up to and including the social behavior of both nonhuman and human forms of life. Demonstrating the complex interrelationships between individuals and systems, both materially and socially, these authors made quite clear that much of human practice has parallels in the organic and social systems of other animals, and that human consciousness and cognitive activity do not replace but are integrated with tacit knowledge to produce understanding in humans.

Maturana and Varela (1992) showed that knowledge was co-determined and limited by an individual's social history and, at a more general level, by the physiological systems of perception and communication as well as, in more complex forms of life, by cultural tools. They gave numerous examples to illustrate how knowledge depended both on an individual's characteristics, such as her or his particular physiology, phenomenology and habitual practice, and on the social system context with which it had co-evolved. Even though they defined knowledge as social practice, it was inescapably both personal and social, since these dimensions were but different perspectives of the same material system, explained in language and other semiotic systems that had co-evolved with the system. One could envisage knowing as exclusively social, personal, or conscious to the exclusion of the other two perspectives only at the risk of getting out of touch with either the material, personal or social constraints on successful adaptation in a material social system composed of particular individuals. These authors showed that the phenomenological experience of individuals was a functioning part of the system just as were the social and material systems. All three were interdependent and their meaning was created by this interdependence. (See also Damasio, 1994, whose neurological research led him to believe that the emotions are dependent on physiology and, as their sociocultural expression which he calls *feelings*, are crucial for effective cognitive and social functioning.)

A theory of classroom teaching and learning that is based on the work of Maturana and Varela and colleagues (including Maturana & Varela, 1992; Varela, Thompson, & Rosch, 1991), espousing a similar ecological theory of the interdependence of conscious and tacit factors in learning, is known by mathematics education researchers as *enactivism* (Begg, 2001; Nunes, Edwards, Matos & Campbell, 1998). Enactivism is seen as a methodology for teaching and learning, a way of enacting knowledge in the classroom.

As I shall go on to explain, all of the theories referred to above had implications for interpreting my research, even though I came to some of them after I had completed the series of studies I will briefly describe in the following section. Furthermore, as well as having theoretical implications for my research, the perspective that I developed in the course of this research had implications for my methodology and for my method of presenting the knowledge I gained in the process of doing my research.

Methodology

To deal with the problem of integrating the different levels of my learning, a narrative approach to reporting the research will be adopted in this paper. My research as a whole can be seen as a series of individual case studies and this paper as a synthesis and integration of discussion resulting from them.

The following is thus a narrative analysis of a research journey during which I conducted five research studies and worked my way towards combining and applying psychological and sociolinguistic theories to the problem of overcoming blocks to motivation and engaging students in learning science to the best of their ability. The five studies can be seen as five steps along the way towards my final conclusion, with each stage resulting in conference papers and/or journal articles This paper thus presents a meta-analysis of my own work, with the goal of achieving a synthesis of the findings from a seemingly disparate group of studies, as I moved from a quantitative to an interpretative to a participatory paradigm and perspective. Table 1 provides a summary of five studies. Briefly, they can be described as follows.

Study 1 was a quantitative case study consisting of an analysis of the results of **a survey** I constructed to test the relationships between student perceptions of science classroom **learning environment factors** and **student learning styles** in this context (Hanrahan, 1994). It resulted from my growing conviction that the teacher-student interpersonal relationship was implicated in problems of student motivation and intellectual engagement in the classroom. It was conceived and carried out, in the context of a preservice elementary teacher education unit, after I had participated in the field research for Study 2 but before I had analyzed the resulting qualitative data in a systematic fashion.

Study 2 was the **first observational classroom study** I did, a case study of a **Year 11 Biology class** (Hanrahan, 1998). Although the classroom observation and interviews took place before I carried out the study reported in Paper 1, the theorizing evident in this paper took longer to develop. My major finding was that, even though the students viewed the class positively, and described themselves as highly motivated to learn, the level of cognitive engagement was affected by two interrelated factors: the control the teacher had over almost all activities, and student beliefs about learning in this context. The data suggested that both intrinsic and extrinsic motivation that could lead to deep involvement in learning were constrained by a preponderance of teacher-centered methods of instruction. A model was proposed relating intrinsic and extrinsic interest to cognitive engagement. It was concluded that more activities should be used that either implicitly or explicitly reinforce positive beliefs about the need for self-direction in learning.

Study 3 was an **observational classroom study highlighting discourse issues in learning science**. It resulted in a paper I delivered at a science teachers' conference about my observations on the mismatch (a better term than 'gap', which suggests a *deficit* rather than a *difference* model) between the expectations of the science curriculum and the language resources of many students (Hanrahan, 1995). It was completed after a period spent observing a Year 8 science teacher and her class, with limited participation on my part. It was at this point that the relevance of my tacit knowledge about language teaching (in relation to English as a school subject, English as a Second Language, and foreign languages) and literacy teaching (in relation to adult learners) began to be tapped. I began to see how much of a mismatch there was between the teacher's assumptions about appropriate discourse practices (including vocabulary level, sentence structure, written genres) for a Year 8 science class, and what most of the Year 8 students in this lower stream class in a high school in a working class area were familiar with.

Table 1 Data and Significance of Research Studies

	Participants	Objective	Focus on psych'l factors	Focus on socio-cult'l factors	Methods	Signif-icance
1	110 elementary preservice teachers	to investigate the relationship between the learning environment & learning styles			survey study, multivariate analysis	cognitive style related to autonomy, affirmation
2	Year 11 Biology teacher & class	to investigate the relationship between student motivational factors and teacher-student interpersonal factors			observation & interview, interpretive analysis	motivational beliefs related to teacher control
2	Year 8 science teacher & class in School 2	to learn about factors influencing student engagement with school science			observation & interview, (implicit) linguistic analysis	loss of motivation related to discourse differences
4/5	Year 8 science teacher & class in School 2	to action research affirmational dialogue journal writing as a way to engage students in reflecting about their experience of learning science			participatory (action) research (PAR), with focus on psychological factors in	non-threatening learning environment enhanced engagement in science
4/5	As for 4	to action research ways of bridging the discourse disparities between teacher and students			PAR, with focus on sociolinguistic factors	demystifying science classroom discourse improved motivation & engagement

Even though students enjoyed the investigations they did in science (and seemed to me to understand the principles involved at least at an intuitive level), it was not long before both they and the teacher realized that the students were performing poorly on tests and were generally at a loss when it came to participating actively in class discussions. Loss of motivation seemed doomed for such students from their very first year of high school.

However, whereas both the teachers and students seemed to see this as the result of a lack of genetic endowment and effort on the part of the students, I could see that a language or literacy teacher could have bridged the language gap and helped the students to participate more in the discourse practices of the science classroom. However, rather than following such a lead, which was barely conscious at this stage, I did not think of changing my original plan (as stated in my doctoral confirmation of candidature document) of researching a personal writing intervention, and when this turned out not to be possible in this school (the teacher went on leave the following semester), I recruited another teacher and "began" my research (this is how both I and others viewed the process at that time) in a different school.

Study 4 is the first research report from my participatory action research (PAR) study with a different Year 8 science teacher and his class in another school in a disadvantaged area, this time a parochial Catholic school. The article that resulted from the study was focused on the findings from the affirmational dialogue journal writing intervention that my host teacher and I action researched collaboratively (Hanrahan, 1999b). The journal writing intervention was designed as a test of the hypothesis I had developed that, for many students the study of science could be very disaffirming, leading to "passivity in class, and a lifelong disaffection with science, outcomes which defeat the long-term purposes of trying to achieve scientific literacy for all students" (p. 699).

In brief the intervention consisted firstly in having students write short diary entries in response to prompts and questions, sometimes about the concepts currently being studied, but just as often about the process of learning science, and their personal experience of—including their feelings about—such things as demonstrations, practical investigations and written tests. The complementary part involved either the teacher or the researcher (myself) writing responses affirming the experiences of the students as legitimate for them at that time, regardless of whether they were positive or negative experiences. These activities took about 10 minutes of class time on average per week, and reading and replying to them took one of us about half an hour weekly. To gain feedback on the students' experience of the dialogue journal-writing activities, after a trial phase of several weeks I used student focus groups.

The resulting article (Hanrahan, 1999b) presented "a new way of framing scientific literacy with a `science for all' goal, based on a nexus of psychological, sociological and critical literacy theory" (p. 699). The intervention itself was found to be successful on a number of fronts. A class who were initially feeling quite discouraged about participating in science remained interested and participated at a satisfactory level all year, and were generally very positive about the affirmational dialogue journal writing, despite their generally very low level of literacy. The teacher developed a new understanding of the difficulties and needs of such students, was better able to elicit real questions and responses from them, and found, to his surprise, that allowing students to express their feelings and thoughts about science, did not lead to behavior management problems. On the contrary, although this class were acting out in most of their other subjects where "behavioral problems were evident" (p. 711), their science teacher described them as "noisy on occasions but very pleasant to teach" (p. 711). He attributed their positive attitude to their having a "firmer input into classroom proceedings" (p. 711) via their dialogue journals. I concluded that an approach that affirms young adolescent science students' experience could lead to a deeper approach to learning for them.

Even though the journal writing proved affirming for students, enhanced communication between the teacher and the students, and resulted in a satisfactory level of motivation, this could not in itself remedy the language mismatch that was just as obvious in this class as in the first Year 8 study (see Study 3 above). My response was to begin gradually, with the cooperation of the teacher, to introduce literacy-teaching activities in the latter part of the journal-writing action research study, with the goal of demystifying the requirements of the science curriculum. Even though it took place concurrently with much of Study 4, because this was a significantly different approach, I have treated it as a study of its own.

Study 5 is thus the second part of the Year 8 action research study. It consisted of trialing language and literacy activities. (See Hanrahan, 1997, 2001, 2002c for a detailed analysis of the activities themselves). Pooling the knowledge that the teacher already had, with my knowledge of language skills that needed to be taught in language and literacy classes, these activities were designed to help students read with better understanding, have significant practice both orally and in writing in using scientific terms that they would be expected to remember, relate what they were learning to their own interests, and generally become less dis-empowered in relation to the curriculum. (By `reading' here I mean such things as deciphering items on the unit tests more accurately, becoming more aware of the structure of textbook chapters and even of the structure of individual paragraphs, and understanding that the meaning of words was context-related.)

In other words, my host teacher and I addressed some of the genres used in the science classroom and introduced activities designed to make visible subtle semiotic cues (including linguistic, graphical and formatting cues) students otherwise tended to ignore. The subsequent analysis of the `literacy' activities we did with the students–what I have collectively called `demystifying activities' (see Hanrahan, 2001, 2002c)–suggests a distinct link between success in learning and students' beliefs about how they should participate in the language practices of the science classroom.

Students responded gratefully to what they saw as a response to their earlier expression of their difficulties and claimed it was helping them to do better in science. In Hanrahan (2001) I wrote:

> [M]any of the students thanked me in later unprompted journal entries for helping them do better on tests and understand things better, saying such things as that I gave them "study ideas", "hints", "clues", "many ways to study for tests", "ways to revise and improve", and let them "compare words and meaning" (p. 12).

The teacher responded by becoming more student-centered and less concerned with covering the curriculum himself and more concerned with helping the students learn with understanding as much as they could.

The results from this study cannot be seen in isolation from those of Study 4, and vice versa, given that they involved the same students and were, for at least part of the time, concurrent. It is my belief that had the `demystifying activities' been used in the absence of earlier feedback from the students about the difficulties they were experiencing with the science curriculum, many of the students would have seen them as even more content being imposed on them rather than as help that they welcomed. This belief is based partly on the research cited above relating autonomy, motivation and self-regulation of learning. It is also based on a comparison with the lackluster results sometimes evident, in my opinion, in classrooms where students are `trained' to use scientific genres in the absence of any evidence that they see any need to do so.

Only in a context of developing trust and respect did the students in this case interpret the provision of these activities as showing concern for their needs. Only then did the students respond to the teacher by paying attention to what he had to show them, and by completing tasks that he set them. In a complementary fashion, only then did the teacher become more interactive in setting tasks such as compiling a list of questions that the students had about investigations. Earlier in the year, we had a situation in which, according to data from the first student focus group discussions, the teacher talked "too fast" and the students got increasingly frustrated as they got left behind. By the end of the school year, we had moved to a situation where a whole period of class time was spent answering the students' questions about an investigation they had carried out the previous day. A somewhat authoritarian classroom climate had evolved into a more democratic one, and the teacher and students were now engaging in `True Dialogue' (cf. Lemke, 1990).

It will be seen from this account of a series of research studies that, unlike case studies that were planned as a series, these studies were more dependent on each other. They evolved organically rather than being pre-planned as a series. My earlier studies (studies 1 to 3) lead to the later ones (studies 4 and 5), and provided not only justification for the matter and manner of my final study, but also additional evidence to consider as I reflected on my research findings. They were not only successive cycles in one (implicit rather than explicit) action research project, with each study being contingent upon my accumulated learning, but overlapping rewritings meant that later studies could influence earlier "findings" that might then affect the overall findings. Nevertheless the issues that were most salient for me when I completed this series of studies were generally those with which I had to come to terms in the final studies where language and literacy issues were uppermost in my thoughts.

Theoretical Implications

A `Biosocial System' Perspective (Hanrahan, 1999a)

My discussion above of Lemke's `ecosocial system' theory and Maturana and Varela's (1992) theory of `the biology of human understanding' should clarify why I could accept that learning was largely the result of social experience but still insist that analysis at the level of individual experience was very meaningful and useful. Such theories, however, described such a broad canvas that they could only touch on action at the level of the interaction between individual human beings, whose cultural, psychological and physiological tendencies might vary considerably. This was problematic for me as a researcher who wanted to help teachers know how to help all students learn and develop. A theory was needed—a *bio*social system theory—that assumed both the sociocultural nature of learning and the significance of the interplay between social and material systems over time, but that also had some explanatory and predictive value at the level of classroom interactions. For me, such assumptions meant paying attention to the psychology of interpersonal communication as well as paying attention to the sociocultural nature of learning.

As a result of my research in the various science education contexts referred to above, I came to a conclusion that students could be helped to engage more fully in learning science when a teacher responded positively to their needs, for example their need to be treated with respect, on the one hand, and their need to have mysterious aspects of the classroom discourse demystified, on the other. Conversely, I concluded that neglecting to pay attention to such needs was likely to result in motivational beliefs and emotional experiences that could have disabling effects on students' motivation, and consequently, on their level of engagement with science. In a biosocial system perspective, the personal and the social are most usefully seen as just two sides of the one coin, and the coin should be seen as having many interactive layers. Among these the emotions could be visualized as a multi-colored filter between the social and the cognitive domains of functioning, or between the physical and socio-cognitive domains. I concluded that teaching that explicitly addressed normally tacit components of the biosocial system allowed more students to participate successfully in learning science than otherwise could.

More specifically, I concluded that science teachers can profitably learn to understand and apply a range of teaching strategies used more commonly in English and other language and literacy classrooms, teaching strategies that have some of their origins in other disciplines, including clinical and humanist psychology and sociolinguistics. These include not only strategies to demystify elements of unfamiliar genres but also strategies designed to help students deal with emotions such as frustration, anxiety, fear of failure, and shame, that can surface when they are confronted by the demands of an unfamiliar discourse system. Such a broadening of a teacher's repertoire allowed a science teacher to take into account aspects of cognitive functioning that have too often been ignored in the past, to the detriment of the cause of "science literacy for all". There are many practical implications and applications of a model such as the biosocial system model. It can provide a broader focus for pedagogy, a new kind of classroom practice, and a research methodology that is honest about how insights are achieved through research.

Practical Implications for Teaching and Learning

Teaching Style and Teaching Strategies

One practical implication is that teachers need understanding of how their teaching style and strategies are likely to affect the epistemological and motivational beliefs of students in general and/or of particular groups of students in their classes.

Not recognizing how particular behaviors could have psychological and physiological effects could mean that a teacher failed to act in a way that facilitated learning and development. For example, if a teacher disaffirmed a student by showing disrespect for her or his values and needs (albeit unintentionally), this would be likely to interact with the individual's beliefs and physiological tendencies and could result in that person feeling alienated, and perhaps de-motivated and de-energized in the short term, and perhaps also, as such experiences accumulated, in the longer term. It would be useful for a teacher to know, for example, that using language that excluded some students was likely to have an effect on their motivation to learn the subject she or he was teaching. Because it assumed a particular audience with whom such students could not identify it would be likely to adversely affect their intellectual engagement with the subject matter (Hanrahan, submitted). Some student-to-student interactions might similarly involve such alienating talk. Hence a teacher still needed to understand and know how to apply psychological theories related to interpersonal communication.

Lemke has addressed this in term of "stylistic norms" in science education. Roth (1992) discussed the likely differential effects of her 'workplace' and 'learning place' orientations to teaching and learning. "Although [originally] I did try to use appropriate discrepant events that would capture students' imaginations, the activities themselves did not seem to be the critical factor. Rather, a more critical aspect of the classroom activities seemed to me to be the kinds of writing and talking that surrounded these activities and that created a classroom community of inquiry and learning." (Roth, 1992, p. 9)

Pintrich, Marx and Boyle (1993) explained how the level of autonomy and choice offered to students, among other factors, influenced the extent to which students would engage with new learning. Blumenfeld, Mergendoller, & Puro (1992) demonstrated that engaging students was not merely a matter of making science fun and enjoyable. Comparing different classes where motivation was high, they showed that such classes still could differ in the level of cognitive engagement. This difference was found to be related to how the teacher provided support for tasks that were pitched at a high cognitive level, and engaged all students in learning for understanding.

Paris and Winograd (1990) reminded us that metacognitive practices are likely to cause emotional reactions, some of them negative—a good reason for some students to prefer not to be metacognitive. Unless teachers are aware of this and help students deal constructively with any negative emotions that result, engaging them in metacognitive practices may be counterproductive. As I wrote in Hanrahan (submitted, p. 7), "A necessary part of successful learning ... was having positive motivational beliefs which would give one sufficient hope to mobilize knowledge which might otherwise remain inert."

My affirmational journal writing research showed that something as simple as allowing students to simply *express* negative emotions in an empathetic environment could be beneficial for their subsequent learning, perhaps because it gave them hope that they could be acceptable members of such a learning community. In summing up a review of motivational research in 1990, Weiner advised researchers both to broaden their thinking to include "frameworks larger than the self and older motivational constructs, such as 'belongingness'" and commented that these " must be brought into play when examining school motivation. He commented further, in line with both sociocultural and psychological theories that "[m]otivation ... is a work-related rather than a play-related concept and must be considered within the context of social values and the goals of the superordinate culture" (Weiner, 1990, p. 621).

In terms of the New London Group (1996) theory of "a pedagogy of multiliteracies", my research supported the necessity of the four factors they promoted. With regard to *Situated Cognition,* I believe that the classroom activities carried out during the action research study created such a community ethos where students felt encouraged to make personal meaning out of their learning experiences in the science class, using the resources of their various lifeworld experiences. Included in such activities would be not only the affirmational dialogue journal writing activities but also the focus group interviews that were used to gather data on what students thought about the journal-writing activities, and any class discussions relating to the journal writing.

With regard to *Overt Instruction*, the various "demystifying activities" that we introduced in the final study are good examples, I believe, of activities that focused students' attention on textual cues that were otherwise too subtle–given the unfamiliarity of the domain–for students to succeed in the reading and writing activities important for satisfactory performance on tests. *Critical Framing* was addressed when we compared the scientific way of describing things with the everyday view while affirming both as legitimate. Further, when we had class discussions about the purpose of science education and schooling, we were allowing the students a space in which they could be critical and retain their dignity in the face of difficult tasks, which might otherwise overwhelm them. We were allowing them to "gain the necessary personal and theoretical distance from what they ha[d] learned." (The New London Group, 1996, p. 87).

Finally, with regard to *Transformed Practice*, in the action research study, I believe practice was transformed such that the interpersonal relations between the teacher and students became more democratic, and the teacher and students and myself became more actively involved in reflecting on teaching, learning, and researching according to our own goals and values, rather than simply (unreflectively) following custom or habit.

Thus all four features of a pedagogy of multiliteracies can be found within the action research study referred to in this paper. I believe that my research, based on a similar combination of psychological, linguistic and social principles, and critical theory, showed one way that it could be put into practice. Our research demonstrated that indeed students can learn more happily and healthily when their individual perspective and sense of themselves as part of a community is taken into account at the same time as they are being made aware of the structure of the social practice of that particular discourse community. Additionally, it demonstrated that raising critical awareness of the "value-centered relations" (the New London Group, p. 86) of the discourse of science teaching and learning can enhance the sense of agency and control over learning, not only for students, but also for the teacher and the researcher.

In relation to the Lingard, et al. (2000) classroom research, the set of "productive pedagogies" they outlined are ones that could be predicted on the basis of my research and the resultant biosocial system model of learning. Supportive teacher-student interpersonal relationships and acceptance of difference (in my case this could refer to difference from the stylistic and discourse norms of science classroom) were as crucial for better communication and improved intellectual engagement as factors more usually associated with intellectual quality, such as providing higher order thinking tasks at an optimal level of difficulty.

Teaching students to `talk science'

More specifically, relating my work to science education, my research demonstrated a way of applying the recommendations made by Lemke (1990), based on his in depth exploration of the language of science classrooms. He proposed several types of activities designed to give students practice in using the language: (a) teaching students to talk science, (b) bridging between colloquial and scientific language, (c) teaching about science and scientific method and (d) helping all students to use science in their own interests. My research has shown how these can be achieved in practice in a regular classroom, using collaborative action research. As has been shown in (Hanrahan, 1997, 2001), all the demystifying tasks we did could be classified according to one or more of these categories.

Where my research went further than the above cases was to show that such theoretical principles based on both psychology and sociocultural theory could be put into practice successfully in the science classroom. As such it complements other research where new metacognitive and constructivist theories were being put into practice, for example, in the PEEL (Project for the Enhancement of Effective Learning) project (cf. Baird & Mitchell, 1986; Baird & Northfield, 1992; see also Loughran, & Northfield, 1996). It complemented these by theorizing in more depth some of the interpersonal aspects that were found to be successful (e.g., developing trust between teachers and students). My research illustrates that, rather than seeing "teaching [as] both an art and a science" (Baird & Mitchell, 1996, p. 294), such personal and interpersonal factors can be seen as integral components of a single, integrated system of learning, not just an eco-social system, but an eco-*bio*social system that includes the psychological with the social.

Participation and Retention in Science

Secondary science teaching which has always tended to act as a filter for the kind of students who will go on to university (Fensham, 2002; Lemke, 1990). Adopting teaching styles and strategies that are affirming and effective for a wider range of students may benefit science in the longer term. Tobias (1990) studied the difference between likely science students who went on to study science and those that did not, and found that the teaching style and approach meant that science did not appeal to suitably qualified students who might otherwise have taken their considerable talents (including highly developed communication skills) into the science arena. Citing the Nobel prize-winning Herschbach—who has been known to ask his theoretical chemistry students to write poetry (Peter Fensham, personal communication, 17/01/03)—she wrote:

> Herschbach believes there are (at least) two kinds of science students: those he calls `sprinters,' students who are quick to grasp new material and who do very well at the kind of manipulations demanded of them in introductory science, and those he calls `long-distance runners,' students who may appear to move more slowly and with greater difficulty, but whose grasp in time is profound. Science, as it is currently taught and evaluated in college, Herschbach believes, favors sprinters over long-distance runners, a significant loss to science, he says, because the latter, if they persist, often make the most important contributions." (Tobias, 1990, p. 61)

The loss in terms of potential science teachers and other science communicators may similarly be raised. We need to consider at what stage we must break into the cycle of impersonal and abstract science education if we want a whole range of professionals to have a high level of science literacy. This might include, not only teachers of science who can engage a wide range of students in the study of science but also mention parents, politicians, economists, and so on, who relate positively to science and who are confident to exercise their judgment in relation to issues of science and technology that affect their communities.

Professional development of teachers

A biosocial system theoretical model has obvious implications for the preparation and professional development of teachers. If belonging to a learning community is also a matter of personal involvement, involving beliefs and associated emotions, and adapting and adopting new discourse practices, then this needs to be taken into account in the way science is taught and also in the way teachers are prepared to teach science. Teachers will need to have a much broader understanding of teaching and learning if they are to involve students in a community of learning where all students needs and values are understood and respected, science is understood in relation to sociocultural issues and language is understood as being a cultural practice relative to the practice of a particular community rather than a unproblematic conveyor of truth.

Another Hanrahan (F. Hanrahan, 2002, p. 2) in summarizing the literature on enactivism, wrote, "In the theory of enactivism educators see that learning requires the learners and teachers to participate in a process that is often messy, punctuated and non-linear. Teaching is recognized as we really experience it." She described how this applied in her own work with preservice teachers who, because of teacher shortages in the area, were eligible to do the mathematics teaching method subject if they had gained more than 20 per cent of the possible marks in the previous year, and consequently often presented with very limited understanding and poor attitudes towards mathematics. She found the theory and practice of enactivism useful for helping such students engage in absorbing conversations about mathematics that continued from one day to the next. This helped them overcome negative attitudes and beliefs about mathematics, helped them develop better numeracy in general, and left them with an improved attitude towards and understanding of mathematics to carry forward into their own classroom teaching practice.

Curriculum Change

As Lemke (2001) did in relation to sociocultural approaches to science teaching, F. Hanrahan (2002) suggested that current school and curriculum structures might not be compatible with such enactivist approaches to teaching and learning. As opposed to the orderly, sequential method that Bernstein concluded was biased in favor of already advantaged students, structures may need to be made more flexible to allow for understanding to be `enacted' in this more disorderly way in classrooms.

One solution is to incorporate these aspects into teacher training courses through short courses. However, if learning is more a matter of acculturation than transmission, this is likely to come to grief as it has in the past at the time at that point in time that graduates come up against the powerful culture of the secondary school science department. Another alternative is to recruit teachers who have had previous careers in another area and hence who have a realistic idea of the place of science in the lives of typical students. My current research is suggesting that complementing a typical science education career path (for example, by breaking it to have children or by working with children and adolescents in some other capacity) is more likely than not to increase a teacher's chances of being able to engage students in learning science with understanding and with a positive attitude.

Research Methodology: Embodied reflexivity

As my theory developed in relation to learning in science education, I found a parallel theory developed in relation to research methodology. I re-examined how I was learning as a researcher and found evidence in my use of personal journal writing that supported the importance of both subconscious personal factors (e.g., emotions, intuitions, associations, dispositions) and sociocultural factors (e.g., biographical data, increased sociolinguistic awareness), alongside conscious analytic and synthesizing processes in my research practice. This is not surprising given that original research is also a process of significant learning and development.

A new methodology thus needed to be developed to be consistent with a theory that stressed the importance of different levels of the biosocial system (in particular, physiological, psychological, psychosocial, and sociocultural factors) for significant learning and development. The method that evolved in the course of my research was originally called eco-bio-social system analysis (Hanrahan, 1999), because of its roots in both ecosocial system theory (Lemke, 1995) and biological theories of human understanding (Damasio, 1994; Maturana & Varela, 1992). I have since called it embodied reflexivity (Hanrahan, 2002a) to capture the fact that the data from my research came from various levels of my awareness (emotions, intuitions, conscious logical processes, social practice) and that these data were being processed at both conscious and subconscious levels of my practice as a human organism within a larger social and material system. (A detailed argument for such a methodology and its implications for research writing can be found in Hanrahan (2003).

Towards a Solution

My research over several studies has explored the relationships between such factors as motivation, teacher-student relationships, language awareness, and identity maintenance, and their impact on engagement in science classrooms. It has resulted in the concept (based on Lemke's (1995) concept of an eco-social system) of a *bio*social system and Maturana and Varela's (1992) theory of "the biology of human understanding", and it has been the goal of this paper to explain and illustrate this notion. Supported by my findings in the context of an unusual combination of psychological and sociocultural theories, I have concluded that a hybrid teaching approach is most likely to be successful in engaging students in learning. Appropriating strategies used in other areas of the curriculum, such an approach takes into account the underlying *biosocial* system, that is, it takes into account how humans function as individual organisms within their eco-social system, and recognizes explicitly some of the subconscious processes involved in both personal commitment and social participation.

When the learning of science is seen as the learning of language, and when language is seen as cultural practice, then we can no longer expect it to happen naturally, without intervention. Then, such learning of language cannot be seen as simply a value-free process, with language being seen as a transparent conveyer of objective meaning. Then it becomes harder to resist the argument that the kind of conceptual change involved is intimately tied up with beliefs and feelings about one's identity as a member of a particular cultural community.

Teaching needs to engage secondary students by allowing that learning is a difficult process involving changes in beliefs and hence needing an empathetic environment and contextualised tasks in a meaningful social situation. Learning in what have been called "content area" subjects needs to reconnect with purpose. In the classroom this means situating content in a context that is meaningful to students. In teacher education this means making learning outcomes for students and motivational factors at least as important as classroom management. Theoretically we need to reconsider the implications for teaching of learning as a purpose-driven activity within a particular social context.

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[i] The latter, according to Taylor (1996) represents cognition as "a dynamic self-organisation of experiential reality rather than an act of discovery of an objective ontological reality", and hence entails culturally relativist notions of truth at the same time as seeing the individual as the author of knowledge.

[ii] This is now the rule rather than the exception. A "science for all" principle in science education policies and curricula has generally been assumed across the world in recent years. It is much harder to find this orientation in practice, however, given resistance on the part of influential academics and leading teachers in the science disciplines (cf. Fensham, 1998, 2002).

[iii] Lemke, 2002, points out that learning and development can be seen as similar processes, though operating over different timescales.

[iv] This paragraph is taken almost word for word from Hanrahan (1998a, p. 5 of 28).

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